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COMMERCIALLY AVAILABLE US DIVERS REGULATORS

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Evaluations were conducted to determine which commercially available open-circuit SCUBA regulators were capable of meeting performance goal standards for Navy use. Bench testing of all candidate regulators was conducted to establish flow patterns and air delivery capacity. Unmanned testing using a breathing simulator at ventilation rates of 22.5, 40, 62.5, 75, and 90 L/min at test depths of 0 to 60 msw (0 to 198 fsw), in 10 msw (33 fsw) increments was conducted to determine work of breathing (WOB) values. Each candidate regulator model was subjected to five runs each. The mean WOB value was then compared to the Performance Goal Standard of 1.37 Joules per Liter (J/L) at 60 msw (198 fsw) by using a one sample T-test with a significance established at $P<0.05$. Testing was conducted in ambient temperature water, approximately 21°C (70°F), with supply pressures of 10.34 and 3.44 MPa (1500 and 500 psi). In addition to this testing, cold water regulators were tested in -2.2°C ± -0.5°C (28°F to 31°F) water to determine candidate regulators propensity for freeze-up. Manned testing was conducted in two phases to subjectively rate regulator performance as well as fit and function. Phase one consisted of dives in the Ocean Simulation Facility (OSF) to 58 msw (190 fsw) and phase two consisted of open sea dives not exceeding 40 msw (130 fsw). Human factors data were collected, analyzed and used as part of the acceptance criteria. Testing conclusively determined that all candidate regulators provided by US DIVERS were capable of meeting the requirements for acceptance by the US Navy.

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GLOSSARY

ANU	Authorized for Navy Use List (NAVSEAINST 10560.2 series)
fsw	Feet of Seawater
J/L	Joules per liter, unit of measure for "Work of Breathing" normalized for tidal volume.
kPa	Kilopascals, newtons/meter^2
MPa	Megapascal
msw	Meters of Sea Water
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
OSF	Ocean Simulation Facility
psi	Pounds per Square Inch
RMV	Respiratory Minute Ventilation
SCFM	Standard Cubic Feet per Minute
SLM	Standard Liters per Minute
WOB	Work of breathing, a computer derived estimate of total respiratory effort obtained when breathing a regulator with a mechanical breathing simulator.

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INTRODUCTION

The requirement for an open circuit SCUBA regulator with the ability to perform within the Performance Goal Standard[1] to a depth of 60 msw (198 fsw) has evolved from changes in diver mission profiles and concern for diver safety in the FLEET DIVER community.

To achieve this end, NEDU was tasked[2] to test and evaluate production models of commercially available open circuit SCUBA regulators to determine which ones meet the US Navy's demanding performance criteria.

U.S. DIVERS, Santa Ana, CA., provided three candidate models for evaluation. The SEA-2, MICRA, and ARCTIC. All three candidate regulators are balanced diaphragm first stages, with a diaphragm actuated demand valve second stage.

UNMANNED EVALUATION

METHODS

Unmanned evaluations of the three candidate regulator models measured Work of Breathing (WOB) levels and compared them to Performance Goal Standards[1], which represent ideal performance levels for open circuit SCUBA regulators. WOB levels are a computer derived estimate of total respiratory effort obtained when breathing a regulator with a mechanical breathing simulator, with units of joules per liter (J/L). Five different regulators were tested for each model. WOB averages represented the mean of the five test results.

The performance goal[1] of 1.37 J/L at 40 msw (132 fsw) with a respiratory minute ventilation (RMV) of 62.5 liters per minute (L/min) and first stage supply pressure of 10.34 MPa (1500 psi) was extended to include 50 and 60 msw (165 and 198 fsw).

For regulators designated by the manufacturer as "for use in cold water," the unextended Performance Goal Standard was used as the target goal for WOB levels.

Testing was also conducted at extended depths, at high ventilatory rates, and reduced first stage supply pressure to characterize the performance of the regulators beyond the current performance standards. These extended tests were not part of the acceptance criteria.

A hierarchical series of standardized testing[3] was conducted on each candidate regulator. Dry bench testing was first conducted to determine if the candidate regulators meet the manufacturer's specifications for air delivery. Inhalation pressures were recorded at 141 SLM ± 1 SLM (5 SCFM) increments from 0 to 849 SLM (0 to

30 SCFM) of flow. A mean of the inhalation pressure (± 1 standard deviation) was derived from five test regulators per candidate model. Bench testing was terminated if cracking pressure varied from manufacturer's specifications by ± 0.13 kPa (0.50 inches of water).

A mechanical breathing simulator (Reimers Consultants, Falls Church, VA) provided sinusoidal breathing loops ranging from 40 to 90 L/min, thus emulating varied diver work rates. Supply pressure to the first stage was maintained at 10.34 MPa (1500 psi) for the downward excursion, then reduced to 3.44 MPa (500 psi) to simulate worst case, for the upward excursion. Work of Breathing loops were taken at 10 msw (33 fsw) increments in both conditions. Test depths ranged from 0 to 60 msw (0 to 198 fsw). Water temperature was maintained at ambient, approximately 21°C (70°F).

For the regulators designated by the manufacturer for cold water use, the water temperature was maintained at -2.2°C ± -0.5°C (28°F to 31°F). In addition to standard Work of Breathing evaluations, cold water regulators were evaluated for freeze-up at 0, 10, 40, and 60 msw (0, 33, 132, and 198 fsw) with the breathing simulator set at 62.5 RMV and supply pressure to the first stage maintained at 10.34 MPa (1500 psi). The candidate regulators were breathed at each incremental depth for a period of thirty minutes with constant monitoring of the breathing loop to determine whether freeze-up of regulator internal/external parts occurred. It is important to note that freezing of second stage components is virtually impossible to prevent. Regulator second stage valve assembly freezing may be attributed to a high dew point of the compressed air being breathed resulting in condensation, residual moisture in the second stage housing, and/or humidified exhaled gas. Unfortunately the specific cause can not be determined.

Based on this, minor freezing of second stage components resulting in minor free flows was considered acceptable. Total failure of second stage components due to severe ice formation and/or any freezing of first stage components was considered unacceptable.

Testing at a specific RMV/depth parameter was terminated if inhalation or exhalation pressure exceeded 4 kPa, the working limits of the pressure transducers currently used in the Experimental Diving Facility. Additionally, if two regulators of one model exceeded 4 kPa within the Performance Goal Standard RMV/depth parameters, testing of that model was terminated.

Descriptive statistics were used to obtain the mean and standard deviation of the data. To determine acceptability of WOB values that were slightly higher than Performance Goal Standard, a one sample T-test with significance established at $P < 0.05$ was performed.

RESULTS

Dry bench testing of the candidate regulators revealed that the SEA-2 was capable of delivering 849 SLM (30 SCFM) at an average inhalation pressure of 0.29 kPa (1.1 inches of water). The MICRA was capable of delivering an average of 701 SLM (25 SCFM) at a high inhalation pressure of 1.27 kPa (5 inches of water). The ARCTIC delivered 850 SLM (30 SCFM) at an average inhalation pressure of 1.20 kPa (4.6 inches of water). Cracking pressures for all three candidate models was within manufacturer's specifications. Flow characteristics for the SEA-2 are shown in Figure 1. Figure 2 shows the flow characteristics for the MICRA, and Figure 3 shows the flow characteristics of the ARCTIC.

WOB values for the SEA-2 at 10.34 MPa (1500 psi) as well as 3.44 MPa (500 psi) supply pressures are summarized in Table 1 and Figures 4 and 5. At the higher supply pressure, WOB levels remained fairly constant at 40 L/min and increased slightly with each increase in test depth at 62.5 L/min, all within Performance Goal Standards. At the extreme ventilatory rates of 75 and 90 L/min, WOB values were well within the acceptable limits to 40 msw (132 fsw). At 75 L/min, 50 msw, the WOB level was only slightly higher than goal, and at 1.56 ± 0.58 J/L should not be considered excessively high. At 90 L/min, WOB values exceeded goal at 40 msw (132 fsw) and were beyond termination criteria at 60 msw (198 fsw). At the lower supply pressure, WOB levels were well within Performance Goal Standard at 40 L/min. At 62.5 L/min, WOB levels were beyond Performance Goal Standard at 60 msw (198 fsw). Acceptable performance was obtained to 30 msw (99 fsw) at 75 L/min and 20 msw (66 fsw) at 90 L/min.

Table 2, and Figures 6 and 7, summarizes WOB values for the MICRA at 10.34 MPa (1500 psi) and 3.44 MPa (500 psi) supply pressures. At the higher supply pressure, WOB levels were well within Performance Goal Standard at both 40 and 62.5 L/min, to 60 msw (198 fsw). Acceptable performance levels were obtained at the higher ventilatory rates of 75 and 90 L/min to depths of 50 msw (165 fsw) and 30 msw (99 fsw) respectively. At the lower supply pressure, acceptable performance levels were maintained at 40 L/min for all test depths. At 62.5 L/min WOB levels increased markedly with each increase in test depth, yet remained within acceptable limits to a depth of 50 msw (165 fsw). The higher ventilatory rates showed high WOB levels, and were not obtainable at 90 L/min, 40 msw (132 fsw) and deeper.

Table 3 and Figures 8 and 9, contain a summary of the WOB values for the ARCTIC at 10.34 MPa (1500 psi) as well as 3.44 MPa (500 psi) supply pressures. At the higher supply pressure, WOB levels at 40 L/min increased with each increase in test depth, yet remained within Performance Goal Standard. At 62.5 L/min, WOB values increased with each increase in test depth. At the Performance Goal Standard depth of 40 msw (132 fsw) for cold water regulators, WOB was 1.44 J/L ± one standard deviation of 0.19. A one sample T-Test, with significance established at $P<$

0.05, was performed and revealed that 1.44 was not significantly higher than 1.37, and therefore acceptable. At the extreme ventilatory rates of 75 and 90 L/min, WOB values were well within the acceptable limits to 20 msw (66 fsw) and 10 msw (33 fsw) respectively. At the lower supply pressure, WOB levels were well within Performance Goal Standard at 40 L/min to a depth of 40 msw (132 fsw). At 62.5 L/min, WOB levels were beyond Performance Goal Standard at 30 msw (99 fsw).

During freeze-up evaluations of the ARCTIC, all five candidate regulators were tested as described in the methods section. Of the five candidate regulators, only one showed minor free-flow at the 10, 40, and 60 msw (33, 132, and 198 fsw) test depths. Based on the minimal amount of free-flow of the one candidate regulator, and no evidence of free-flow from the other four candidate regulators, this was considered acceptable.

MANNED EVALUATION

Manned data was collected per two NEDU Test Plans[3,4] where divers subjectively rated candidate regulator performance, as well as regulator fit and function during open sea dives to a maximum depth of 39.6 msw (130 fsw) as well as in the NEDU Ocean Simulation Facility (OSF) to a depth of 58 msw (190 fsw).

All diver subjects were military divers with between 2 to 24 years of SCUBA diving experience and are highly familiar with the operation and use of SCUBA equipment.

HUMAN FACTORS EVALUATION

Diver subjects used the Human Factors Questionnaire (Appendix A), to evaluate fit and function subjectively as well as work of breathing in candidate regulators.

All ratings are on a 1-6 scale, with 1 being "extremely poor" and 6 being "excellent."

A total of thirty-five divers completed questionnaires following each dive to evaluate the three candidate regulator models.

RESULTS

Ten diver subjects conducted open sea dives to evaluate the **SEA -2**. All work of breathing parameters were rated as *adequate* or better by all divers. Figure 10 shows the overall inhalation and exhalation effort as uniformly *acceptable* or better. Of the fit and function parameters rated, two divers rated the mouthpiece as *not quite adequate*, and one rated it as *poor*. Range of motion was rated as *not quite adequate* by one diver, and one diver rated buoyancy of the regulator as *not quite adequate*.

The overall comfort with using this regulator is shown in Figure 11, where one diver rated it as *unacceptable* while nine divers rated this parameter *acceptable* or better.

OSF dives conducted to evaluate the **SEA -2** were completed by twenty diver subjects. Of the work of breathing parameters rated, one diver rated head up exhalation as *poor*. One diver rated prone exhalation *poor*. One diver rated supine inhalation as *not quite adequate* while one diver rated it as *poor*. Supine exhalation was rated as *extremely poor* by one diver. As shown in Figure 12, the overall inhalation effort was rated as *unacceptable* by two divers, and *acceptable* or better by the remaining eighteen divers. All divers rated the overall exhalation as *acceptable* or better. Fit and function evaluations show one diver rating the mouthpiece as *extremely poor*, and one diver rated range of motion as *poor*. Figure 13 shows the overall comfort with using this regulator rated as *unacceptable* by three divers, and *acceptable* or better by the remaining seventeen divers.

Fifteen diver subjects conducted open sea dives to evaluate the **MICRA**. All work of breathing parameters were rated as *adequate* or better by all divers. Figure 14 shows the overall inhalation and exhalation effort rated as *unacceptable* by one diver, and *acceptable* or better by the other fourteen diver subjects. Of the fit and function parameters rated, one diver rated the mouthpiece as *not quite adequate*. Range of motion was rated as *not quite adequate* by two divers, and one diver rated buoyancy of the regulator as *poor*. The overall comfort with using this regulator is shown in Figure 15, where all divers rated this parameter *acceptable* or better.

OSF dives conducted to evaluate the **MICRA** consisted of sixteen diver subjects. Of the work of breathing parameters rated, one diver rated supine inhalation as *not quite adequate* while one diver rated it as *poor*. Supine exhalation was rated as *extremely poor* by one diver. One diver rated head up exhalation as *poor*. Two divers rated prone exhalation *poor*. As shown in Figure 16, the overall inhalation effort was rated as *unacceptable* by two divers, and *acceptable* or better by the remaining fourteen divers. Three divers rated the overall exhalation as *unacceptable*, with the remaining thirteen divers rating it as *acceptable* or better. Fit and function evaluations show one diver rating the mouthpiece as *poor*, and two divers rated range of motion as *poor*. Figure 17 shows the overall comfort with using this regulator rated as *unacceptable* by two divers, and *acceptable* or better by the remaining fourteen divers.

Sixteen diver subjects conducted open sea dives to evaluate the **ARCTIC**. All diver subjects rated all of the work of breathing parameters as *acceptable* or better. Figure 18 shows the overall inhalation and exhalation effort uniformly rated as *acceptable* or better by all sixteen diver subjects. Of the fit and function parameters rated, three divers rated the mouthpiece as *not quite adequate*. The overall comfort with using this regulator is shown in Figure 19, where all divers rated this parameter *acceptable* or better.

OSF dives conducted to evaluate the **ARCTIC** consisted of twenty diver subjects. Of the work of breathing parameters rated, five divers rated supine inhalation as *not quite adequate* while one diver rated it as *poor*. Supine exhalation was rated as *extremely poor* by one diver. One diver rated head up exhalation as *poor*. Four divers rated 45° face up as *not quite adequate*. As shown in Figure 20, the overall inhalation and exhalation effort was rated as *acceptable* or better by all divers. Fit and function evaluations show all divers rating these parameters as *acceptable* or better. Figure 21 shows the overall comfort with using this regulator rated as *acceptable* or better by all twenty divers.

CONCLUSIONS/RECOMMENDATIONS

It is important to note that the establishment of performance criteria to 60 msw (198 fsw) is solely a Navy requirement and is not an endorsement by NEDU that casual/standard SCUBA dives be conducted to such depths with these regulators. Additionally, performance goals are not acceptance criteria for diving equipment approval and diving equipment that exceed these goals are not necessarily unsafe for diver use.

Work of Breathing results obtained from the SEA-2 clearly identify this as a superior performing regulator, capable of surpassing the extended Performance Goal Standard, even at reduced supply pressure. Human Factors results provide compelling evidence of acceptability by Navy divers, with a combined total of twenty-six out of thirty diver subjects rating the overall comfort of this regulator as *acceptable* or better.

Based on the results obtained during unmanned and manned evaluations of the SEA-2, recommend that this regulator be <u>approved</u> for use to a depth of 58 msw (190 fsw).

Work of Breathing results for the MICRA identify this regulator as being capable of surpassing the extended Performance Goal Standard. Acceptable performance can be expected even at the higher ventilatory rates to depths of 50 msw (165 fsw). Human Factors evaluations show a combined total of twenty-nine out of thirty-one diver subjects rating their overall comfort with using this regulator as *acceptable* or better.

Based on the results obtained during unmanned and manned evaluations of the MICRA, recommend that this regulator be <u>approved</u> for use to a depth of 58 msw (190 fsw).

Work of Breathing results obtained for the ARCTIC initially show this regulator to have exceeded the Performance Goal Standard for cold water regulators. Statistical analysis of the work of breathing values obtained show that although 1.44 J/L is higher than the Performance Goal Standard of 1.37 J/L, there is no significant difference in the two values. Therefore, this regulator is capable of meeting the Performance Goal Standard for cold water regulators. The minor free-flow evidenced from one of the candidate regulators during the freeze-up evaluation may be attributed to condensed water vapor (high dew point), residual moisture, and/or humidified exhaled gas, but can not be specifically determined. It is important to note that the cold water kit functioned properly in that no freezing of the first stage occurred. Human Factors evaluations show overwhelming evidence of acceptability with a combined total of thirty-five out of thirty-six diver subjects rating their overall comfort with using this regulator as *acceptable* or better.

Based on the results obtained during unmanned and manned evaluations of the ARCTIC, recommend that this regulator be **approved** for use to a depth of 40 msw (132 fsw) in water temperatures not below -2.2 ± -0.5°C (28 to 31°F).

REFERENCES

1. J. R. Middleton and E. D. Thalmann, *Standardized NEDU Unmanned UBA Test Procedures and Performance Goals*, NEDU TR 3-81, Navy Experimental Diving Unit, July 1981.

2. NAVSEA Task 94-10, *Commercial Diving Equipment Test and Evaluation*, January, 1994.

3. *Evaluation of Commercial Open Circuit SCUBA Regulators (Unmanned/Manned)*, NEDU Test Plan 93-21 (Limited Distribution), Navy Experimental Diving Unit, May 1993.

4. *Evaluation of Commercial SCUBA Regulators OSF Bounce Dive Series to 190 FSW (Manned)*, NEDU Test Plan 92-44 (Limited Distribution), Navy Experimental Diving Unit, November 1992.

TABLE 1

SEA-2 OPEN CIRCUIT SCUBA
REGULATOR WOB RESULTS
MEAN ± 1 STANDARD DEVIATION
EXPRESSED IN JOULES PER LITER (J/L)

10.34 MPa (1500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.60 ± 0.11	0.65 ± 0.13	0.67 ± 0.14	0.72 ± 0.15
10	0.70 ± 0.13	0.79 ± 0.17	0.83 ± 0.18	0.87 ± 0.21
20	0.76 ± 0.14	0.82 ± 0.16	0.83 ± 0.23	0.89 ± 0.29
30	0.73 ± 0.16	0.79 ± 0.22	0.86 ± 0.27	1.13 ± 0.39
40	0.75 ± 0.13	0.81 ± 0.22	1.01 ± 0.31	2.14 ± 0.71
50	0.76 ± 0.15	0.86 ± 0.26	1.56 ± 0.58	2.55 ± *
60	0.72 ± 0.16	1.06 ± 0.34	1.85 ± 0.46	#

3.44 MPa (500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.65 ± 0.12	0.68 ± 0.14	0.72 ± 0.13	0.74 ± 0.15
10	0.74 ± 0.14	0.83 ± 0.16	0.88 ± 0.16	0.95 ± 0.16
20	0.74 ± 0.14	0.87 ± 0.17	0.88 ± 0.22	1.03 ± 0.33
30	0.78 ± 0.18	0.87 ± 0.22	1.03 ± 0.30	1.68 ± 0.59
40	0.81 ± 0.14	0.99 ± 0.28	1.54 ± 0.51	2.2 ± *
50	0.81 ± 0.15	1.27 ± 0.43	1.82 ± 0.28	#
60	0.78 ± 0.18	1.97 ± 0.67	#	#

# Denotes WOB value beyond termination criteria

TABLE 2

MICRA OPEN CIRCUIT SCUBA
REGULATOR WOB RESULTS
MEAN ± 1 STANDARD DEVIATION
EXPRESSED IN JOULES PER LITER (J/L)

10.34 MPa (1500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.61 ± 0.06	0.67 ± 0.07	0.64 ± 0.06	0.57 ± 0.10
10	0.69 ± 0.05	0.75 ± 0.10	0.72 ± 0.15	0.68 ± 0.13
20	0.77 ± 0.08	0.86 ± 0.14	0.85 ± 0.13	0.96 ± 0.28
30	0.87 ± 0.06	1.00 ± 0.20	1.03 ± 0.29	0.99 ± 0.28
40	1.00 ± 0.05	1.04 ± 0.16	1.03 ± 0.23	1.56 ± 0.38
50	1.05 ± 0.08	1.11 ± 0.15	1.29 ± 0.14	1.56 ± 1.26
60	1.10 ± 0.04	1.18 ± 0.10	2.25 ± 0.49	#

3.44 MPa (500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.67 ± 0.05	0.70 ± 0.06	0.68 ± 0.06	0.66 ± 0.05
10	0.76 ± 0.06	0.82 ± 0.10	0.80 ± 0.09	0.82 ± 0.11
20	0.86 ± 0.10	0.96 ± 0.15	1.05 ± 0.17	1.19 ± 0.29
30	1.00 ± 0.11	1.14 ± 0.22	1.22 ± 0.25	1.44 ± 0.34
40	1.09 ± 0.09	1.25 ± 0.22	1.39 ± 0.25	#
50	1.14 ± 0.07	1.35 ± 0.16	2.38 ± 0.29	#
60	1.22 ± 0.08	1.81 ± 0.25	1.89 ± 0.25	#

# Denotes WOB value beyond termination criteria

TABLE 3

ARCTIC OPEN CIRCUIT SCUBA REGULATOR WOB RESULTS MEAN ± 1 STANDARD DEVIATION EXPRESSED IN JOULES PER LITER (J/L)

10.34 MPa (1500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.81 ± 0.18	0.87 ± 0.19	0.91 ± 0.19	0.97 ± 0.20
10	0.90 ± 0.19	1.03 ± 0.20	1.14 ± 0.23	1.22 ± 0.26
20	1.02 ± 0.19	1.19 ± 0.17	1.31 ± 0.23	1.55 ±0.22
30	1.13 ± 0.16	1.35 ± 0.18	1.56 ± 0.23	2.37 ±0.80
40	1.20 ± 0.14	1.44 ± 0.19	2.55 ± 0.94	#
50	1.32 ± 0.14	2.34 ± 0.67	#	#
60	1.37 ± 0.15	#	#	#

3.44 MPa (500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	0.85 ± 0.23	0.96 ± 0.26	0.99 ± 0.23	1.06 ± 0.21
10	0.97 ± 0.23	1.07 ± 0.22	1.15 ± 0.25	1.28 ± 0.28
20	1.08 ± 0.18	1.29 ± 0.26	1.47 ± 0.26	1.84 ± 0.32
30	1.17 ± 0.16	1.59 ± 0.27	2.11 ± 0.48	3.01 ± *
40	1.31 ± 0.12	1.89 ± 0.41	2.68 ± *	#
50	1.42 ± 0.24	1.94 ± *	#	#
60	1.54 ± 0.30	#	#	#

# Denotes WOB value beyond termination criteria

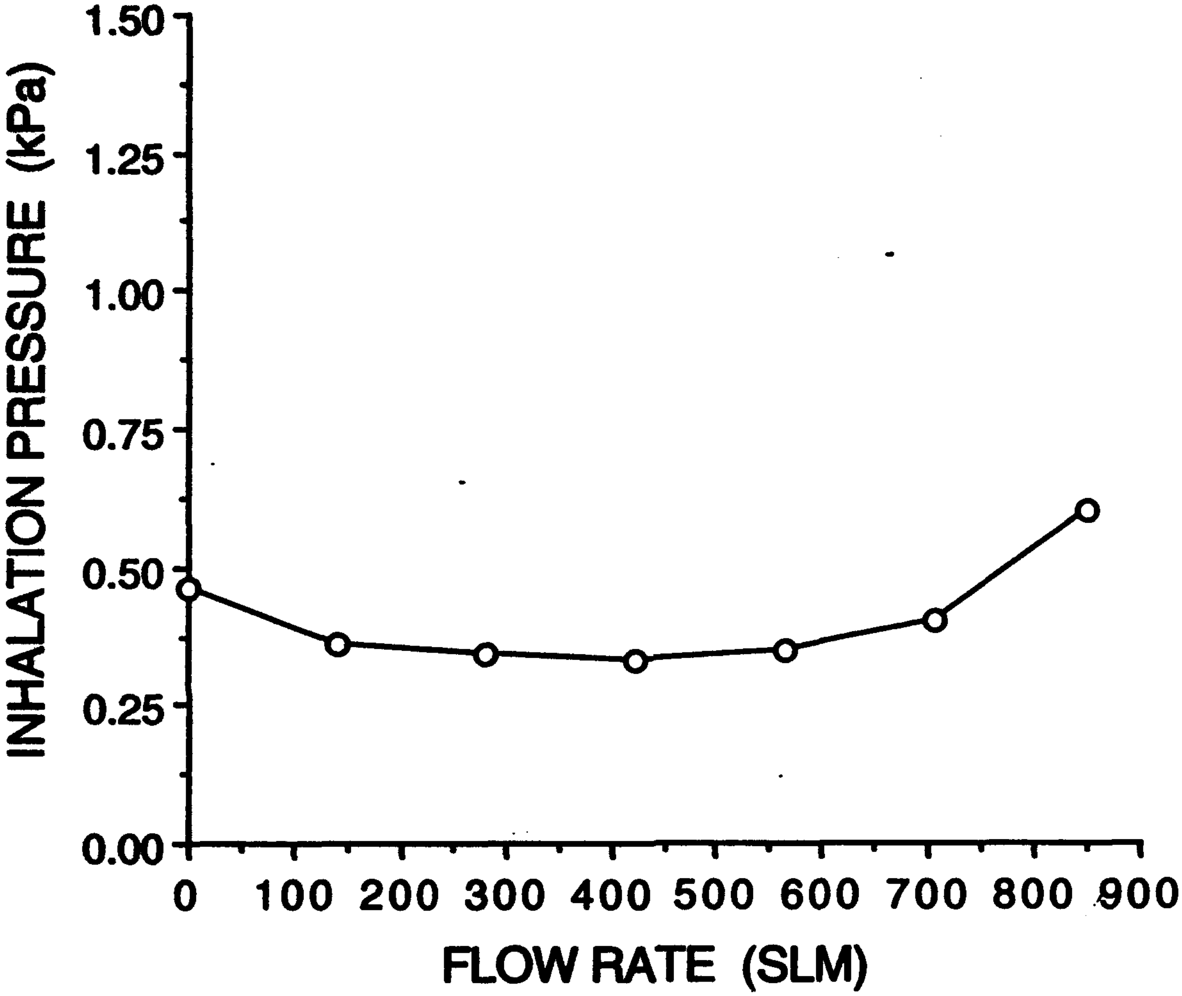

Figure 1. SEA-2 Flow Characteristics

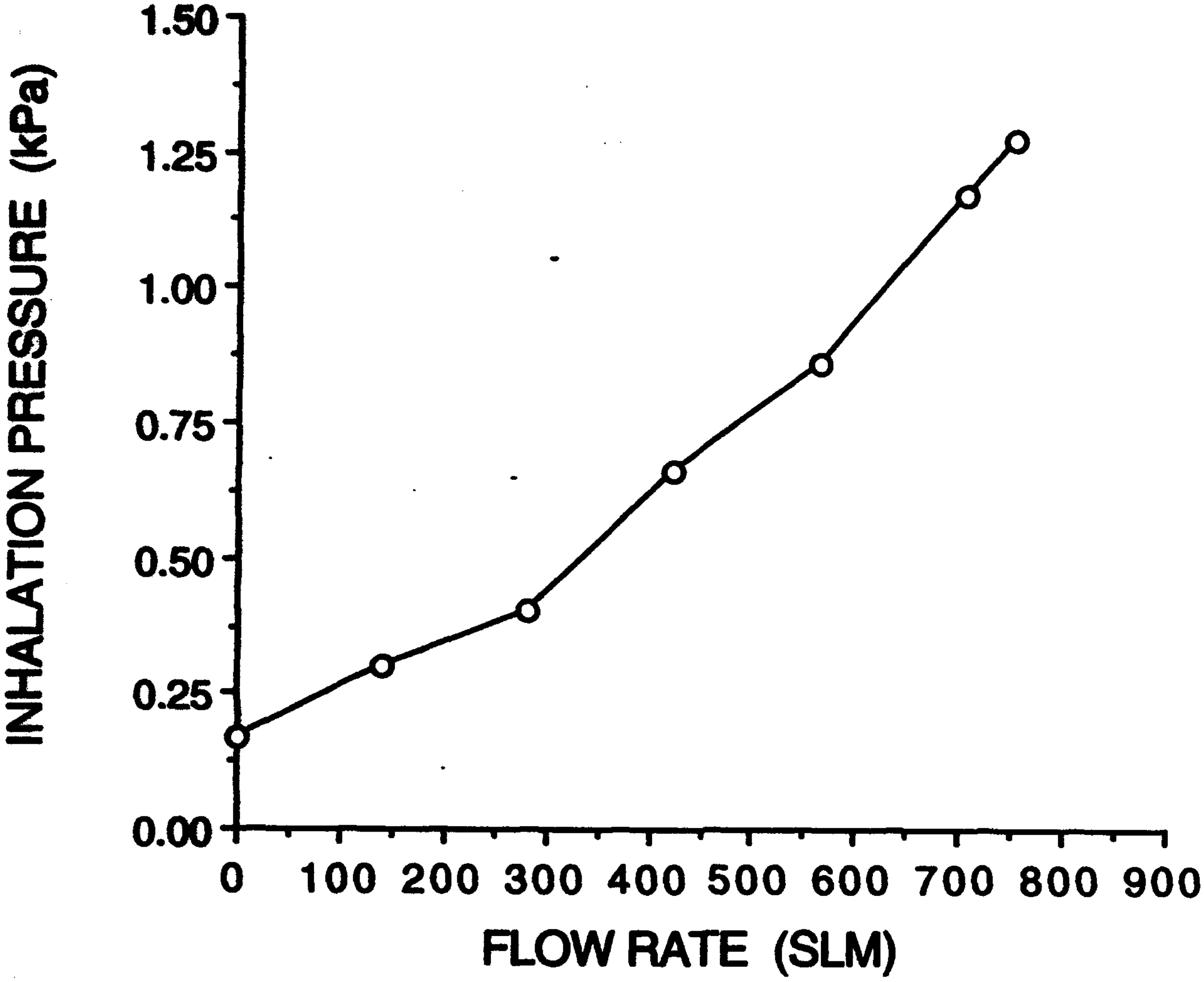

Figure 2. MICRA Flow Characteristics

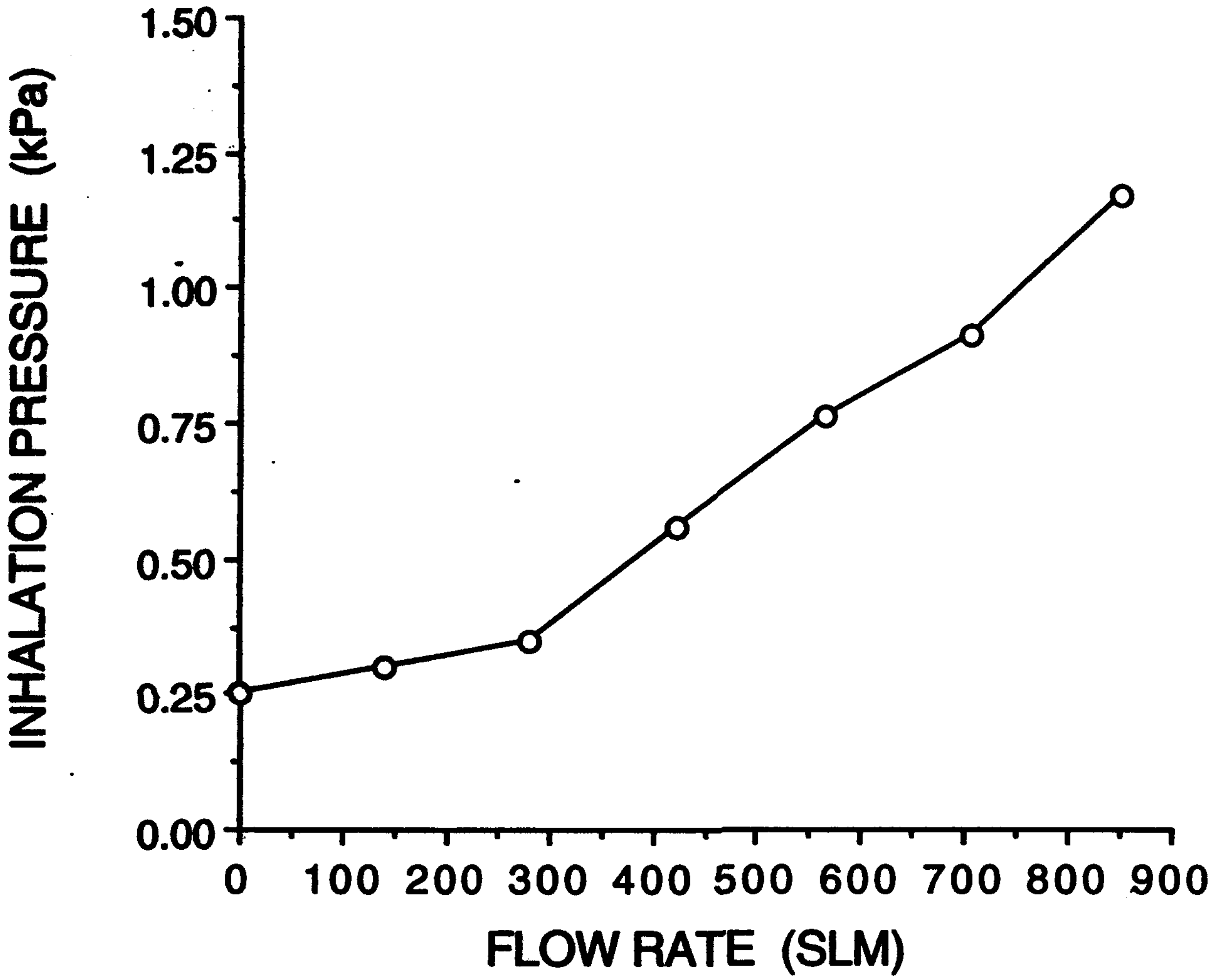

Figure 3. ARCTIC Flow Characteristics

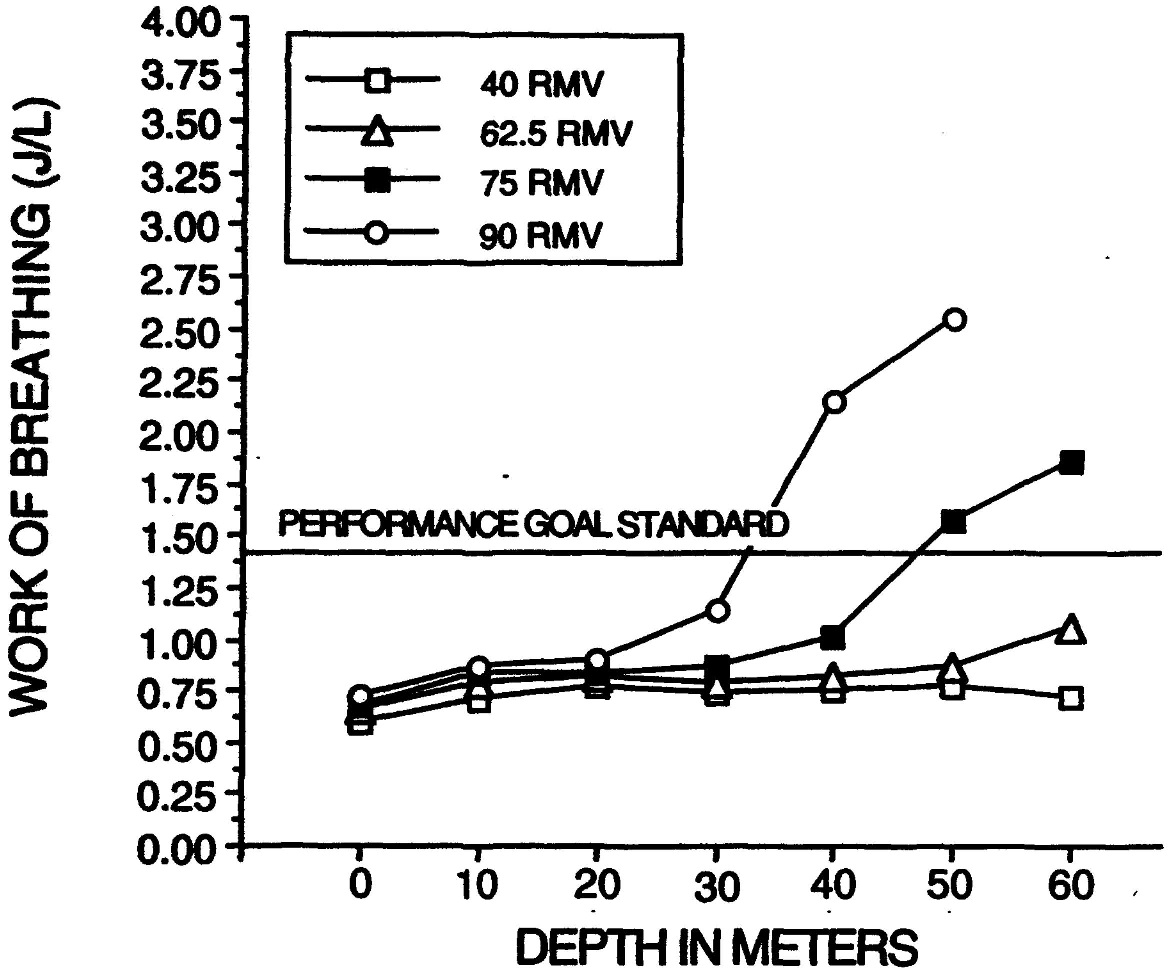

Figure 4. SEA-2, 10.34 MPa (1500 psi) Supply Pressure

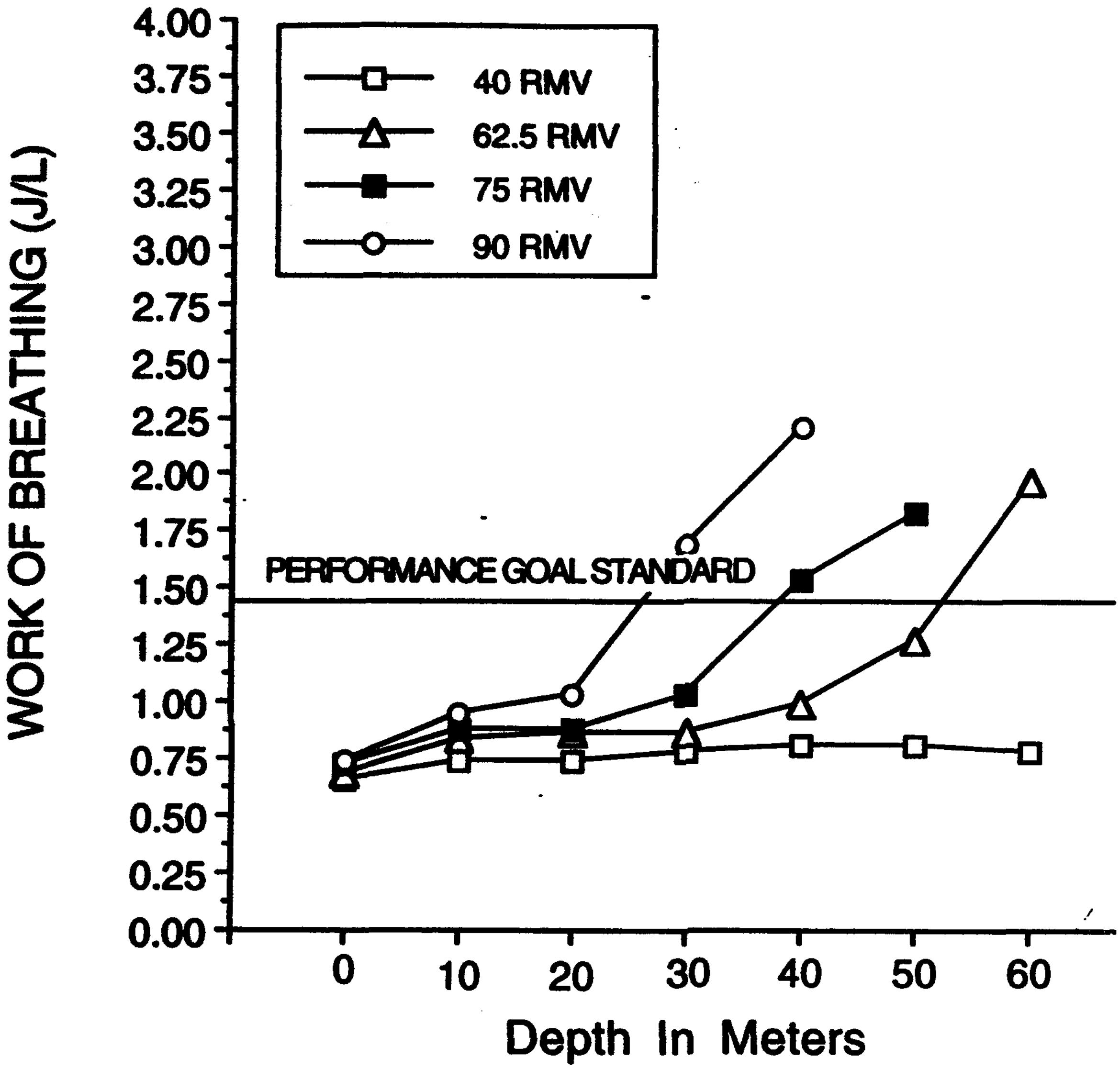

Figure 5. SEA-2, 3.44 MPa (500 psi) Supply Pressure

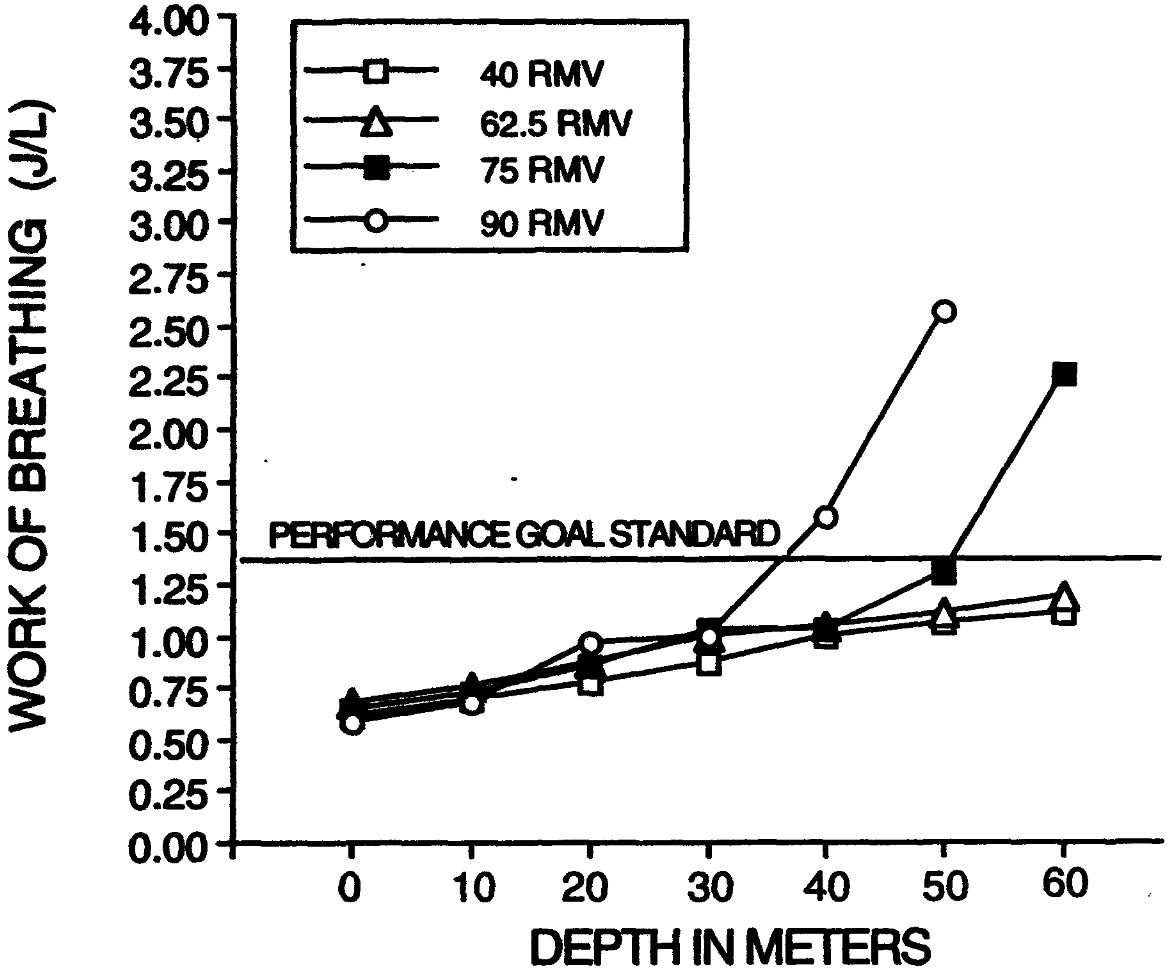

Figure 6. MICRA, 10.34 MPa (1500 psi) Supply Pressure

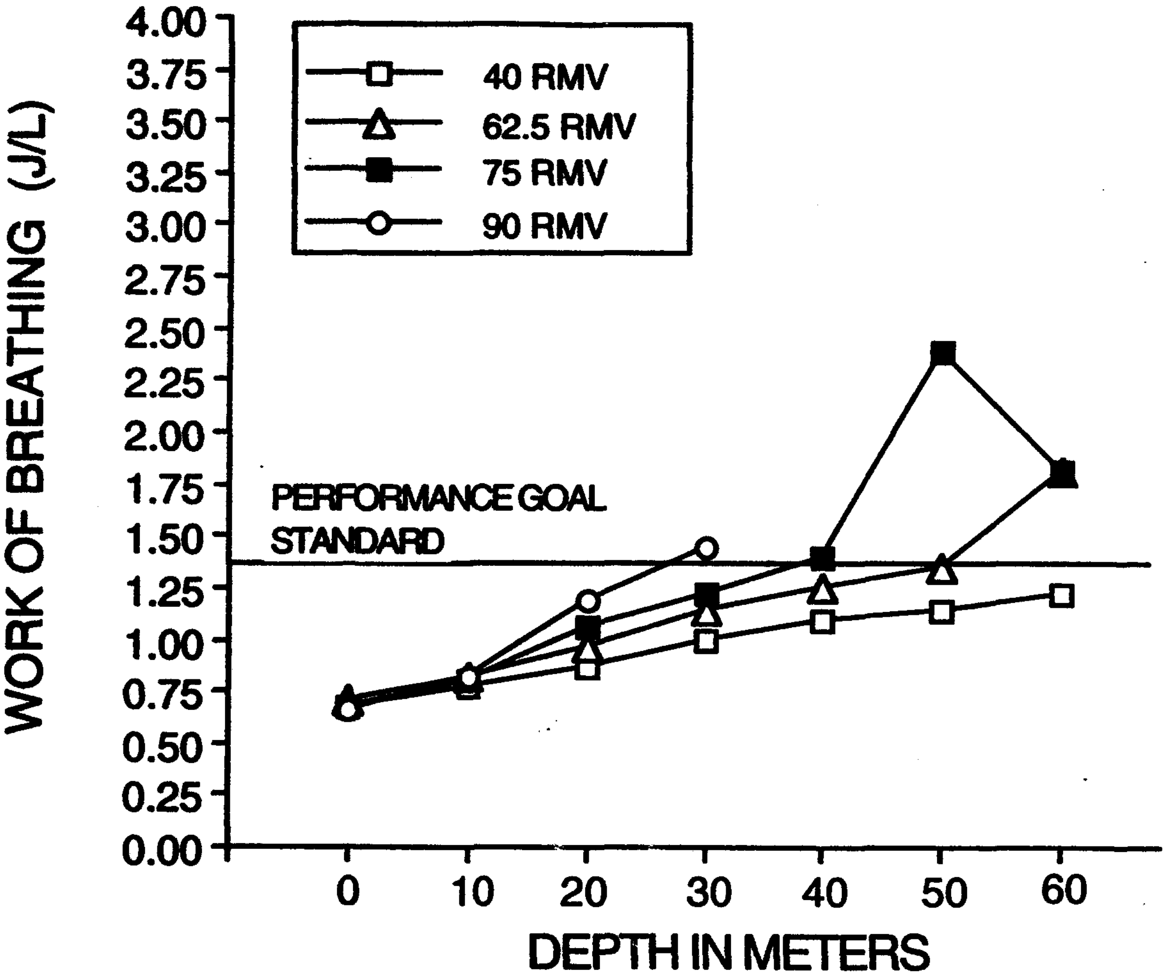

Figure 7. MICRA, 3.44 MPa (500 psi) Supply Pressure

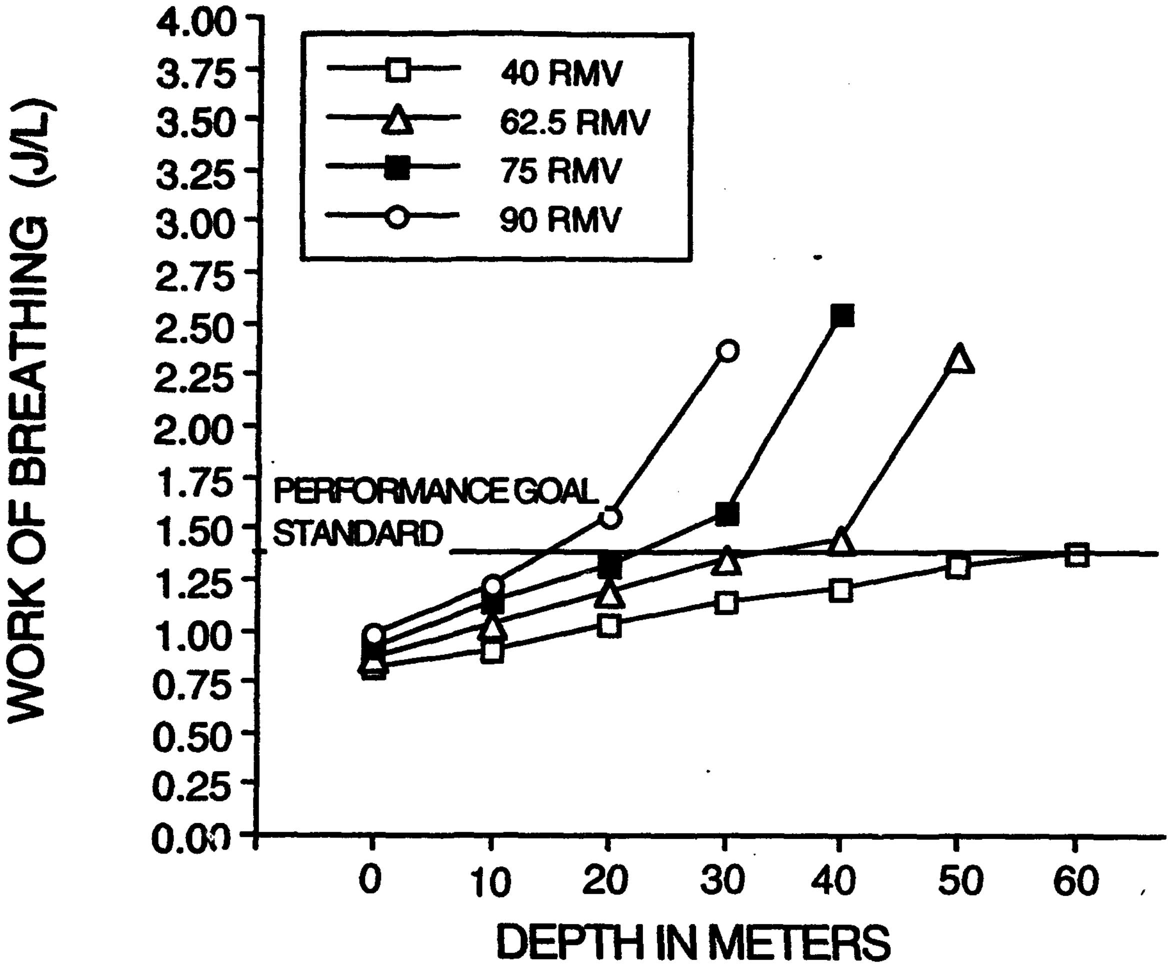

Figure 8. ARCTIC, 10.34 MPa (1500 psi) Supply Pressure

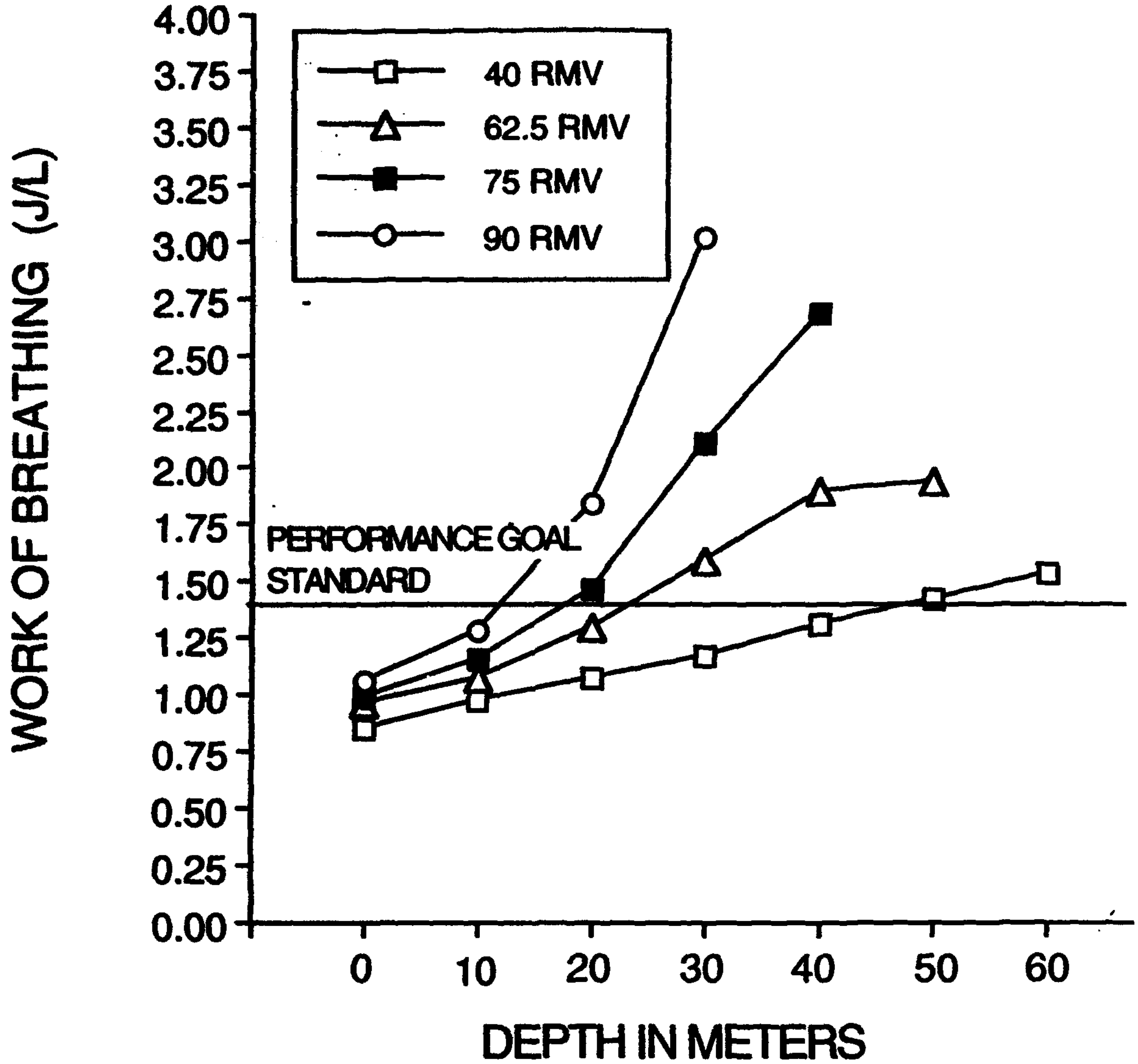

Figure 9. ARCTIC, 3.44 MPa (500 psi) Supply Pressure

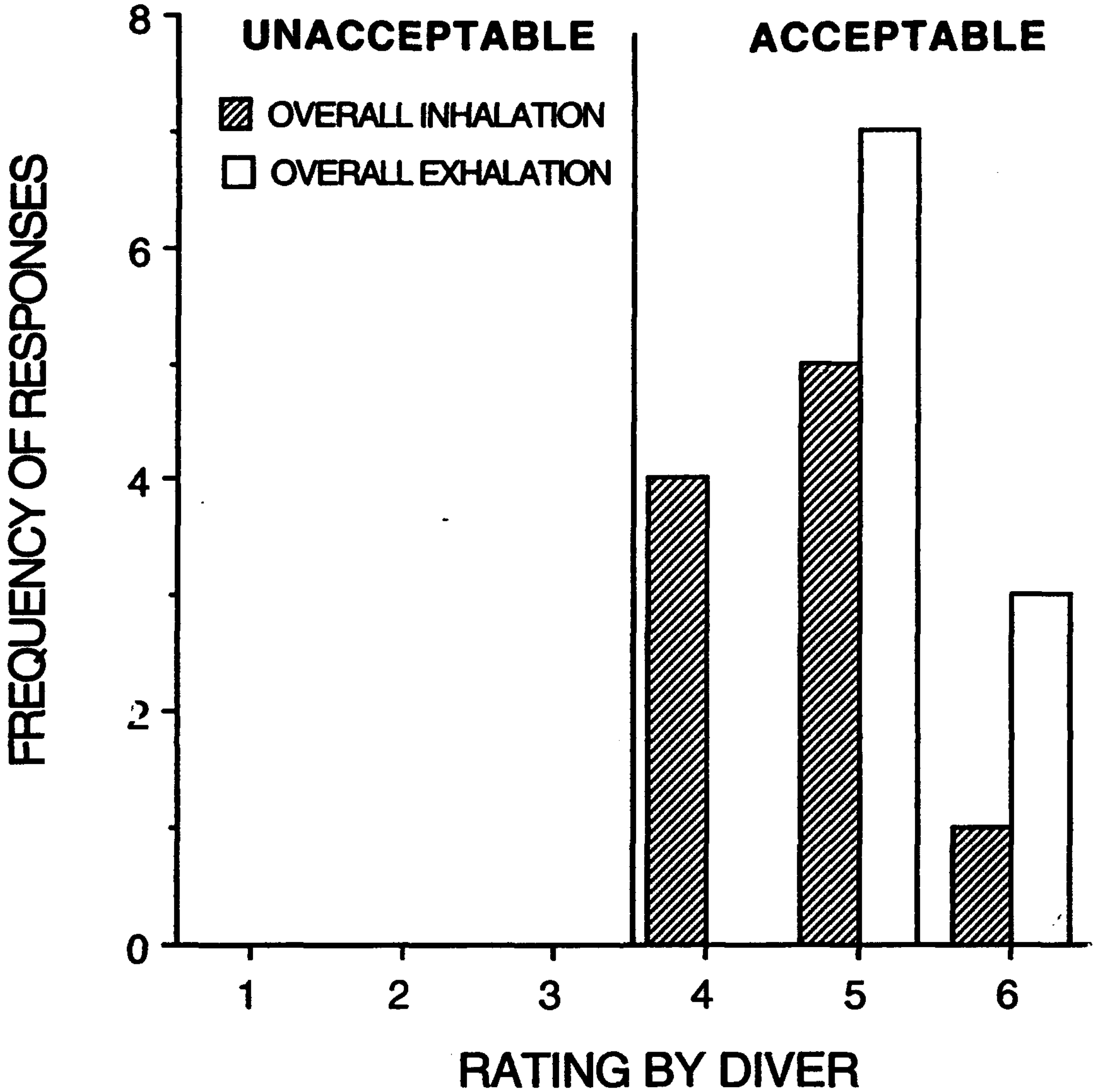

Figure 10. SEA-2, Open Sea, Overall Inhalation/Exhalation

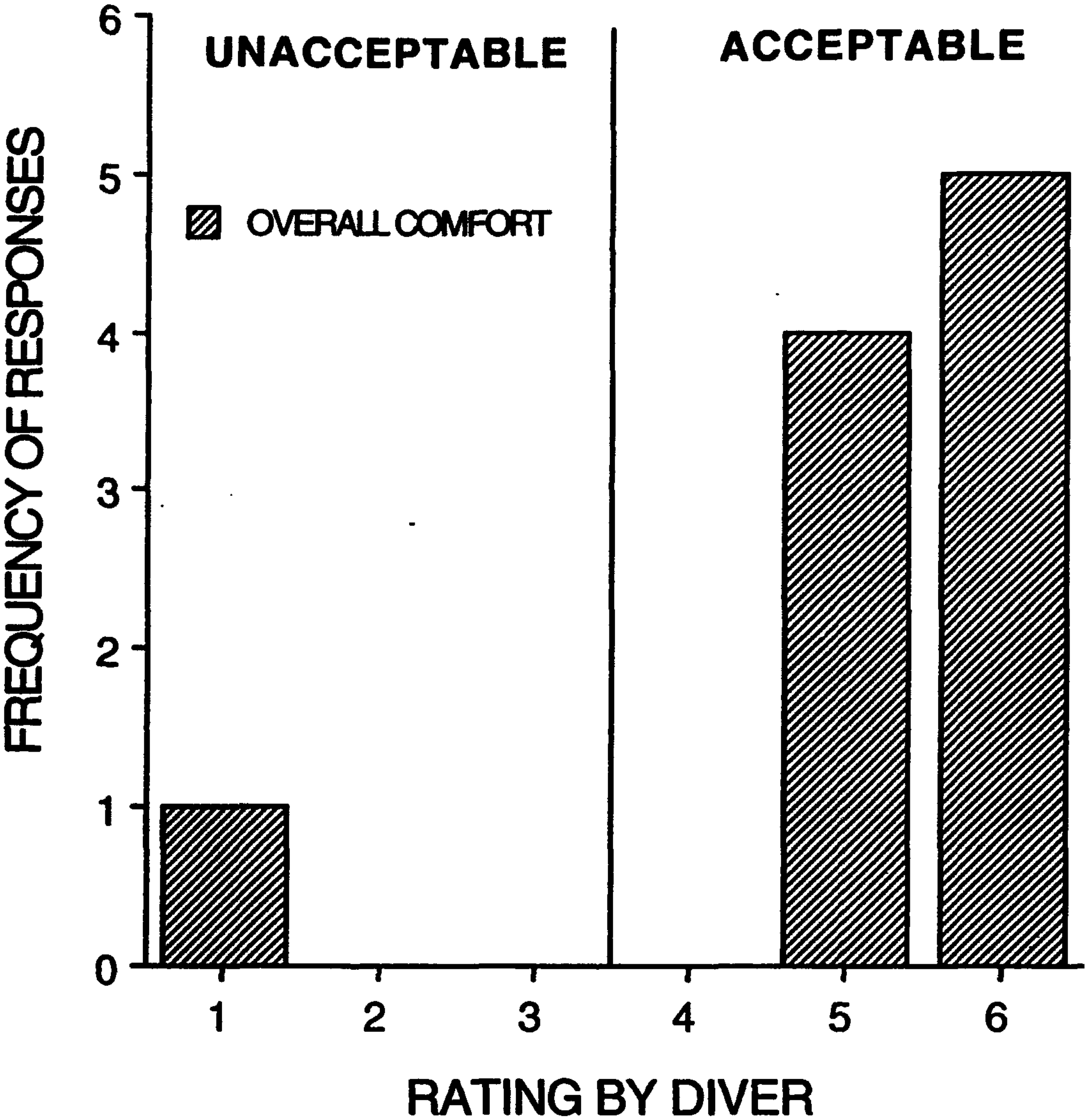

Figure 11. SEA-2, Open Sea, Overall Comfort With Use

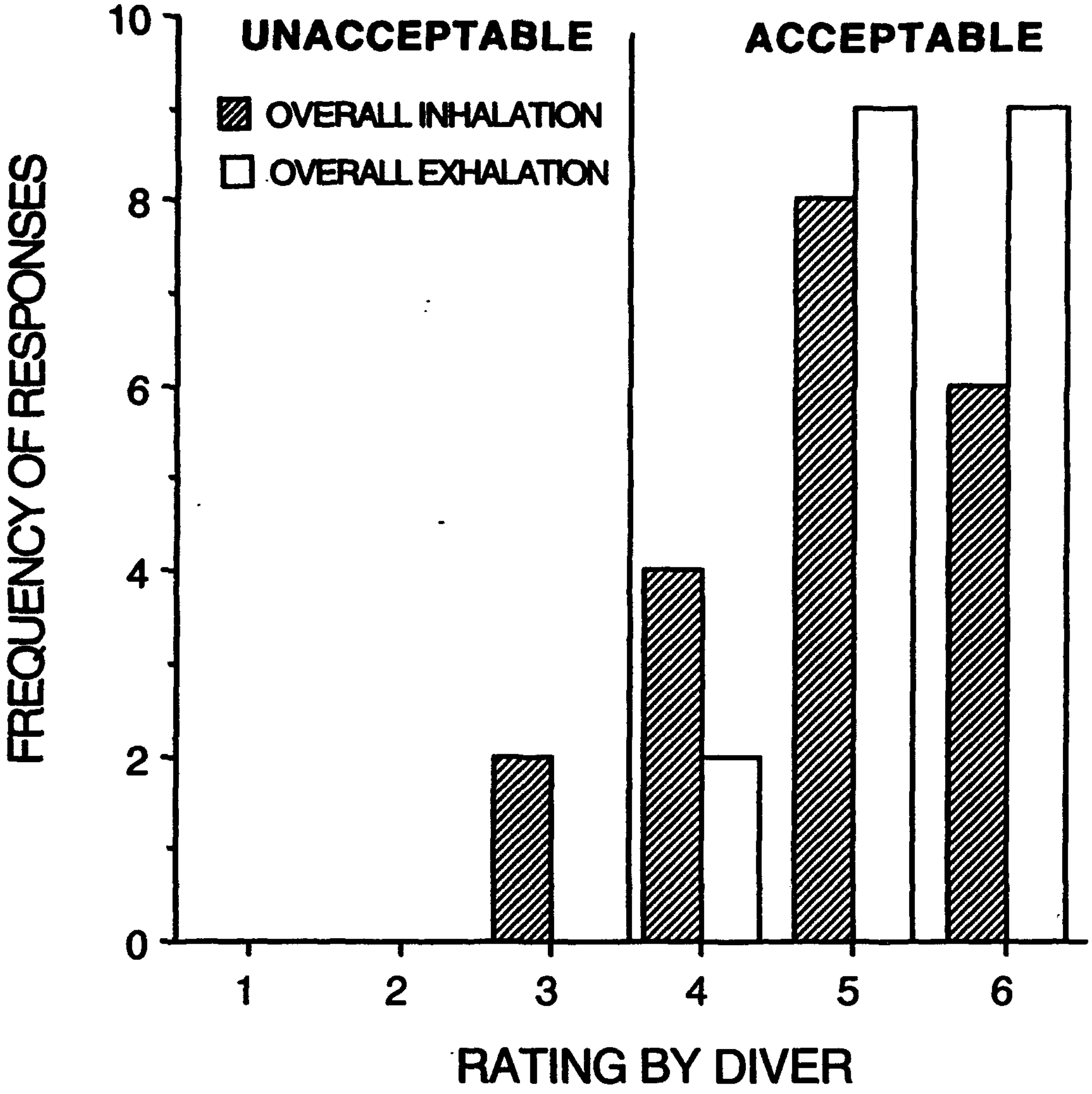

Figure 12. SEA-2, OSF, Overall Inhalation/Exhalation

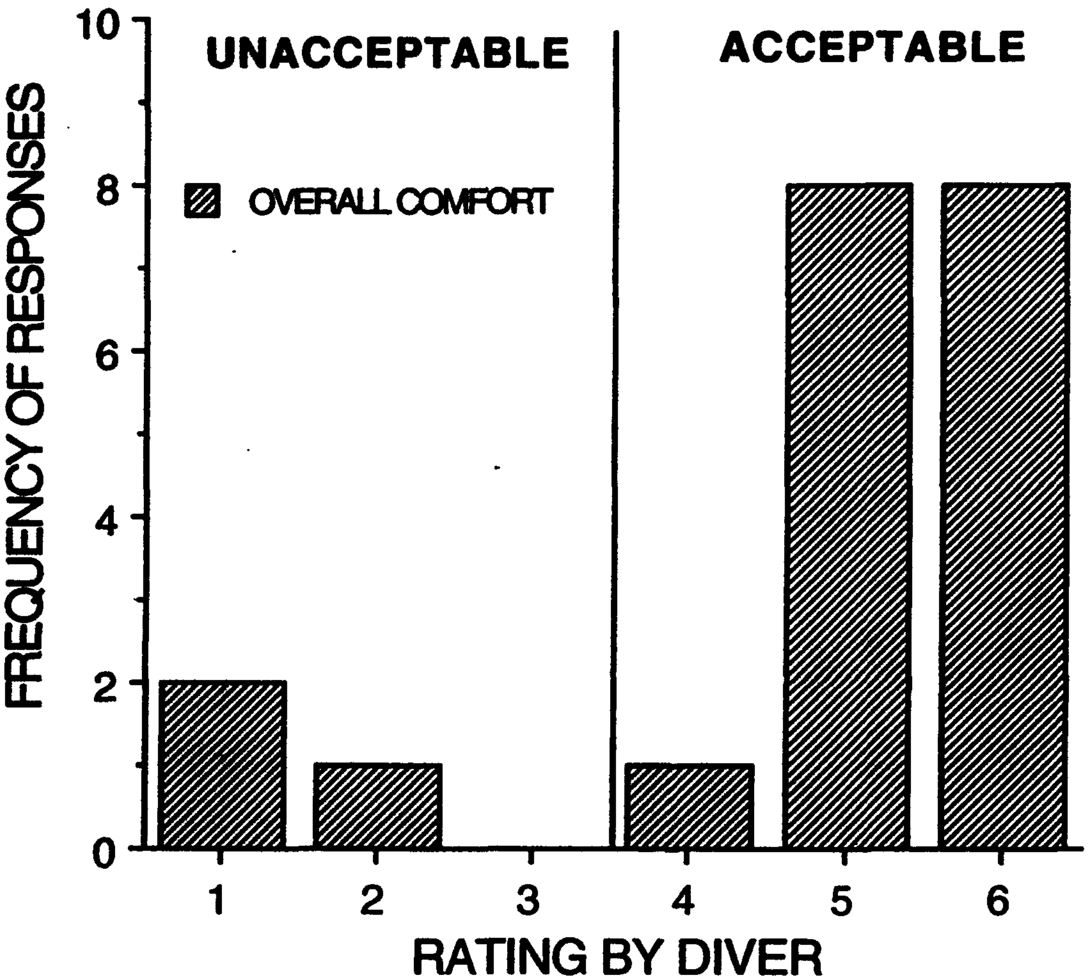

Figure 13. SEA-2, OSF, Overall Comfort With Use

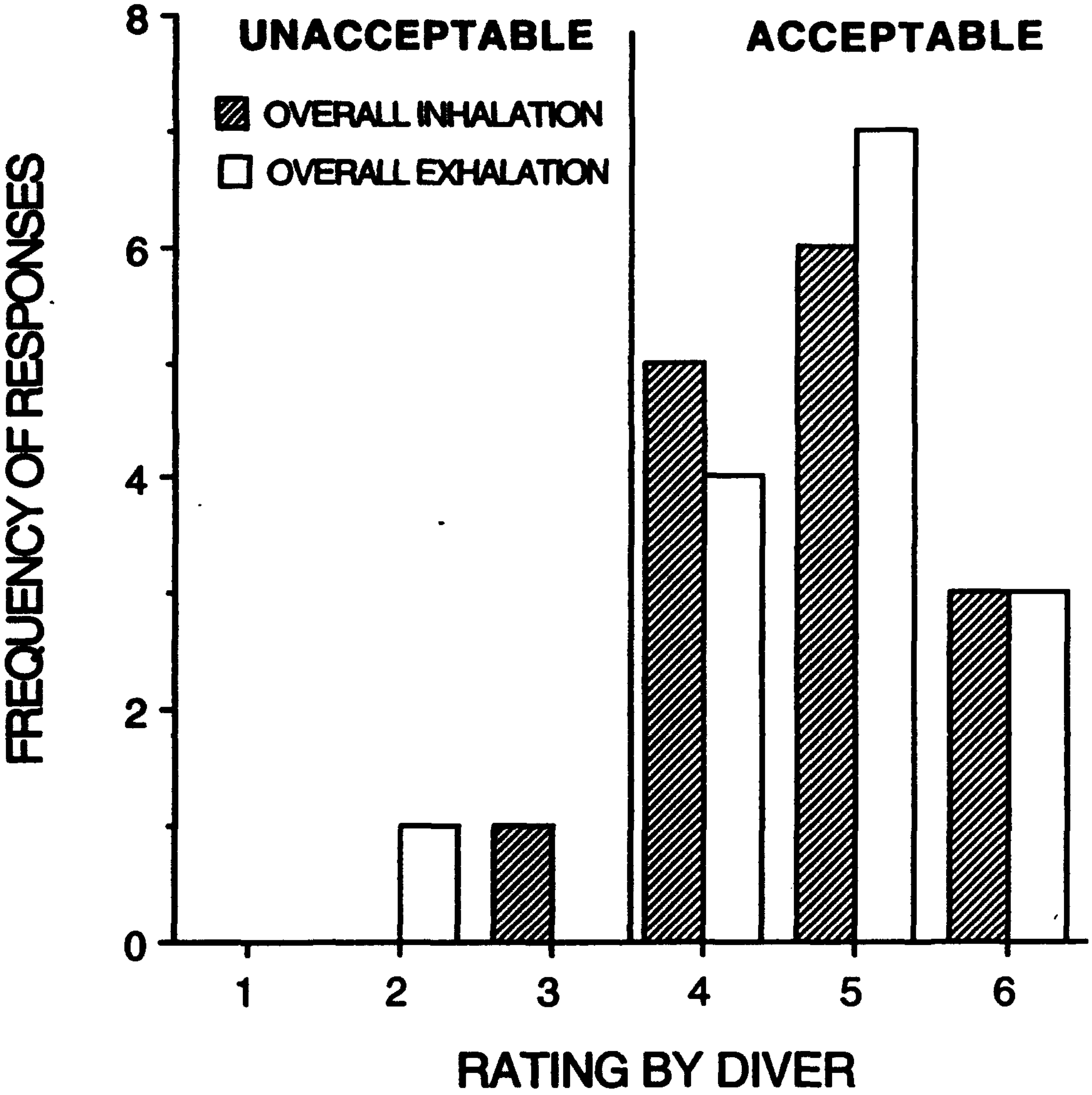

Figure 14. MICRA, Open Sea, Overall Inhalation/Exhalation

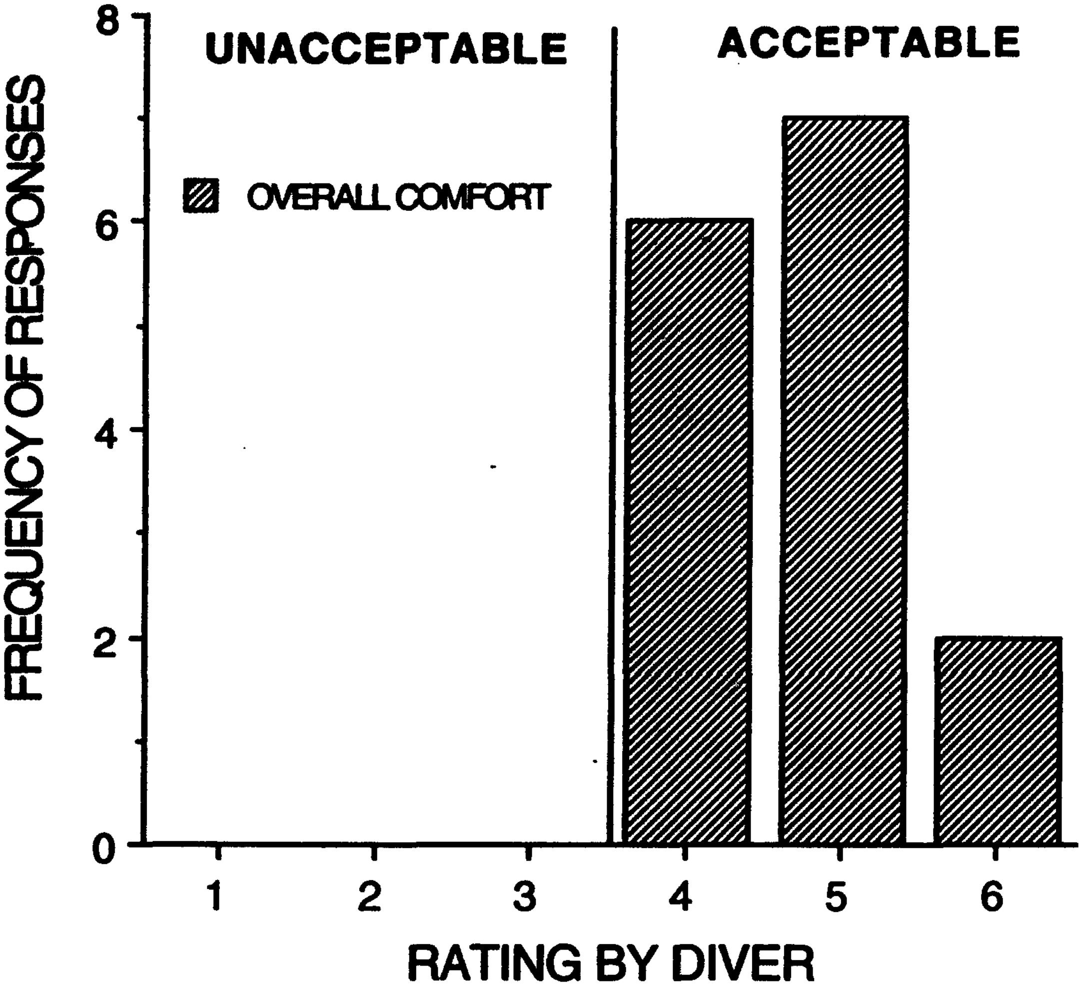

Figure 15. MICRA, Open Sea, Overall Comfort With Use

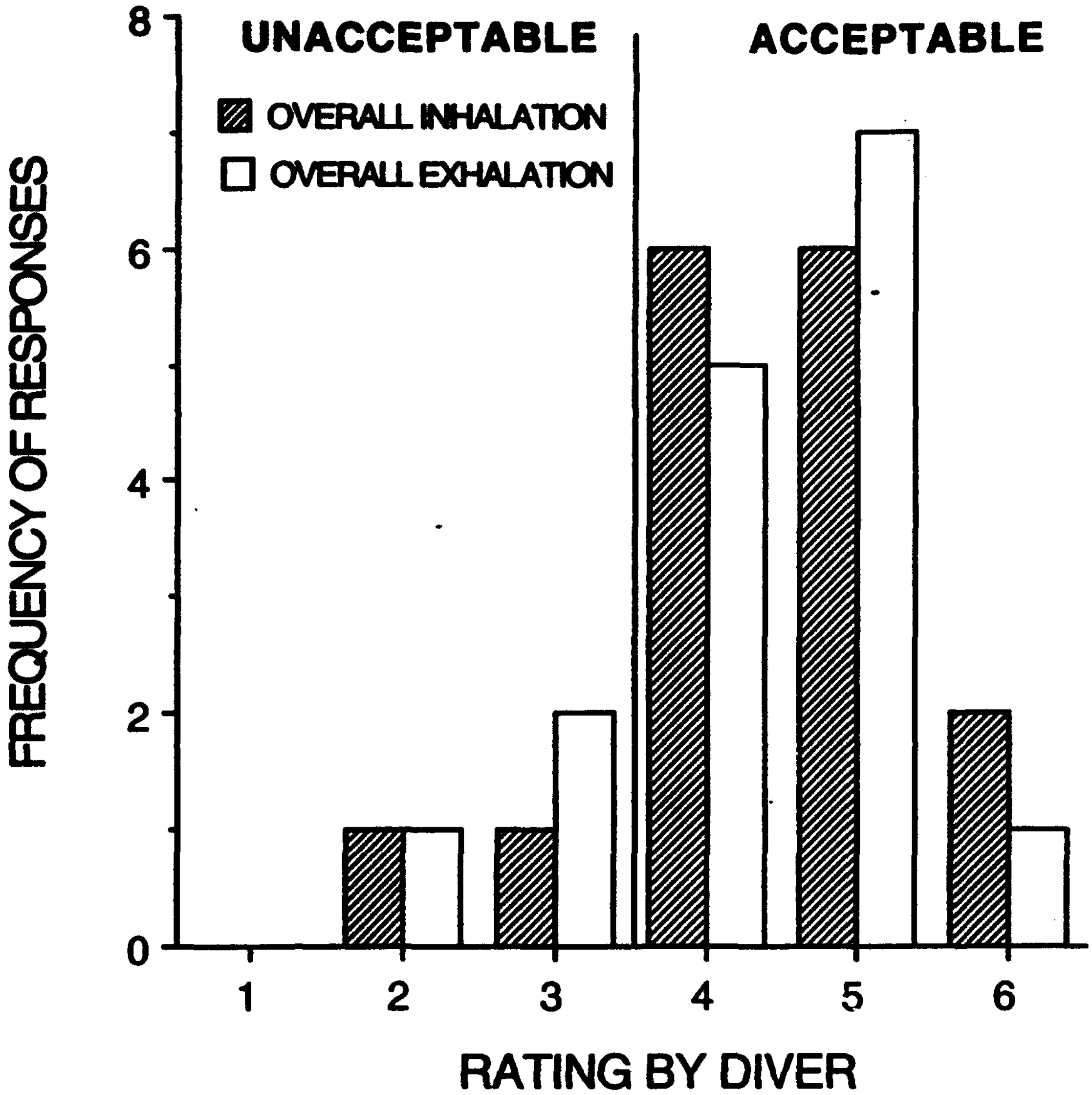

Figure 16. MICRA, OSF, Overall Inhalation/Exhalation

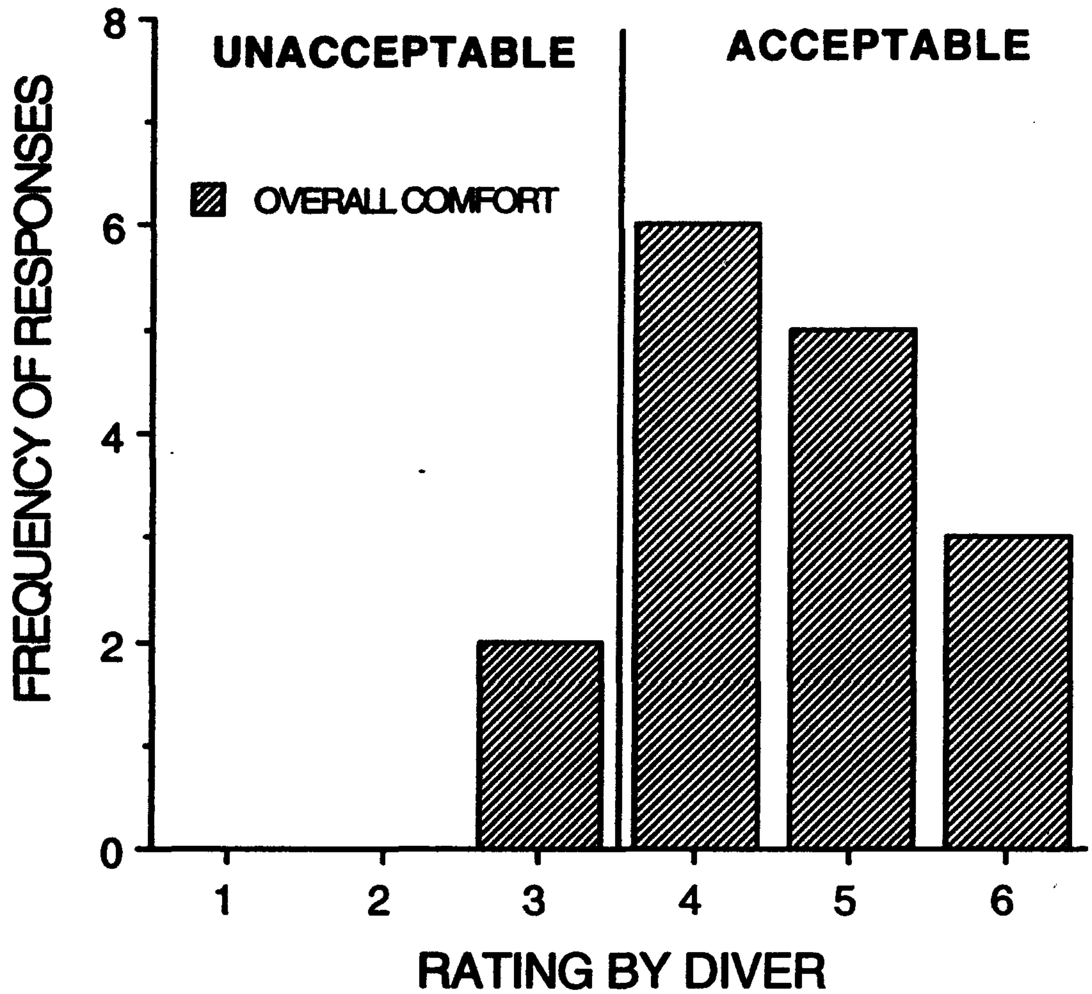

Figure 17. MICRA, OSF, Overall Comfort With Use

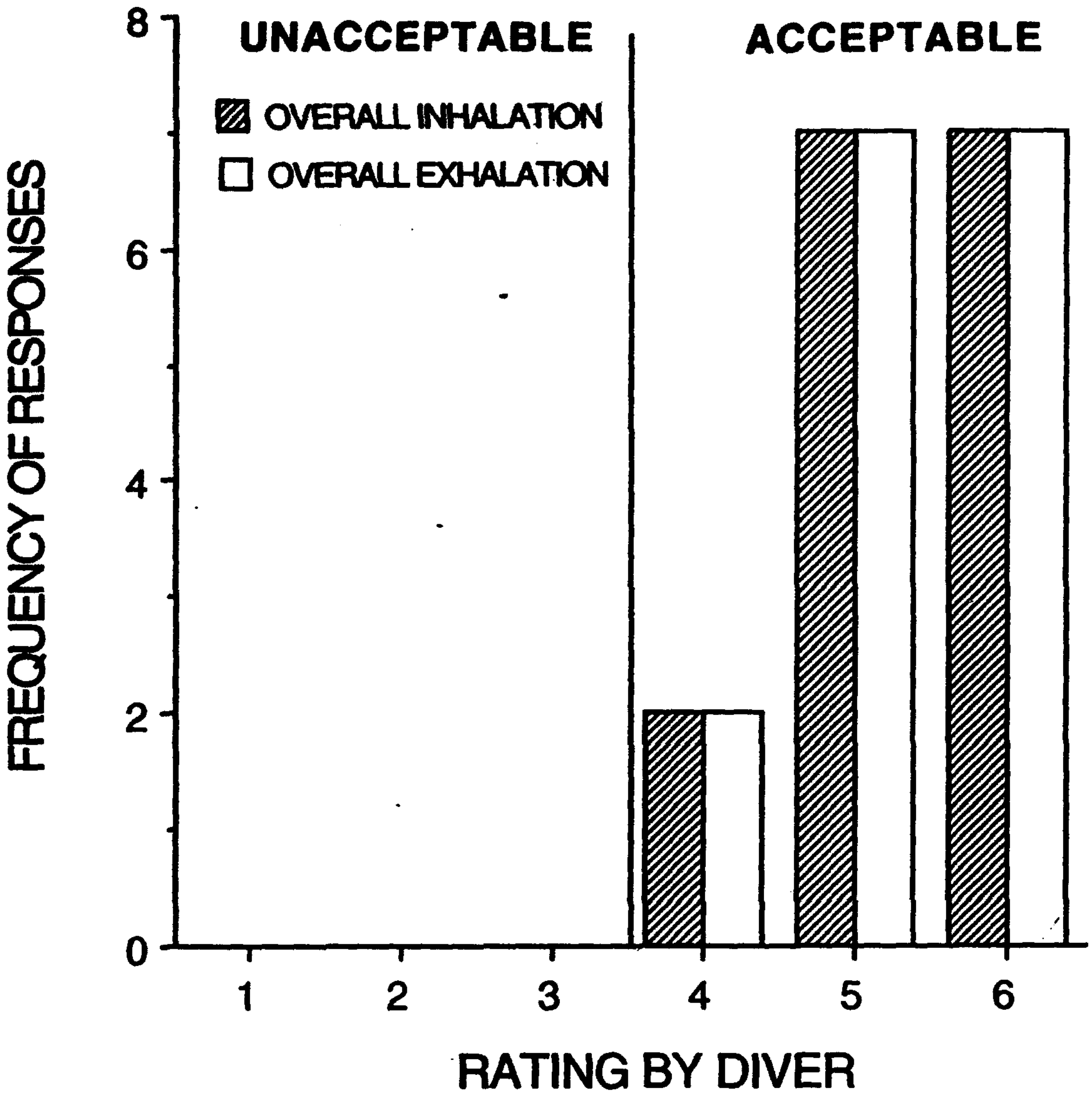

Figure 18. ARCTIC, Open Sea, Overall Inhalation/Exhalation

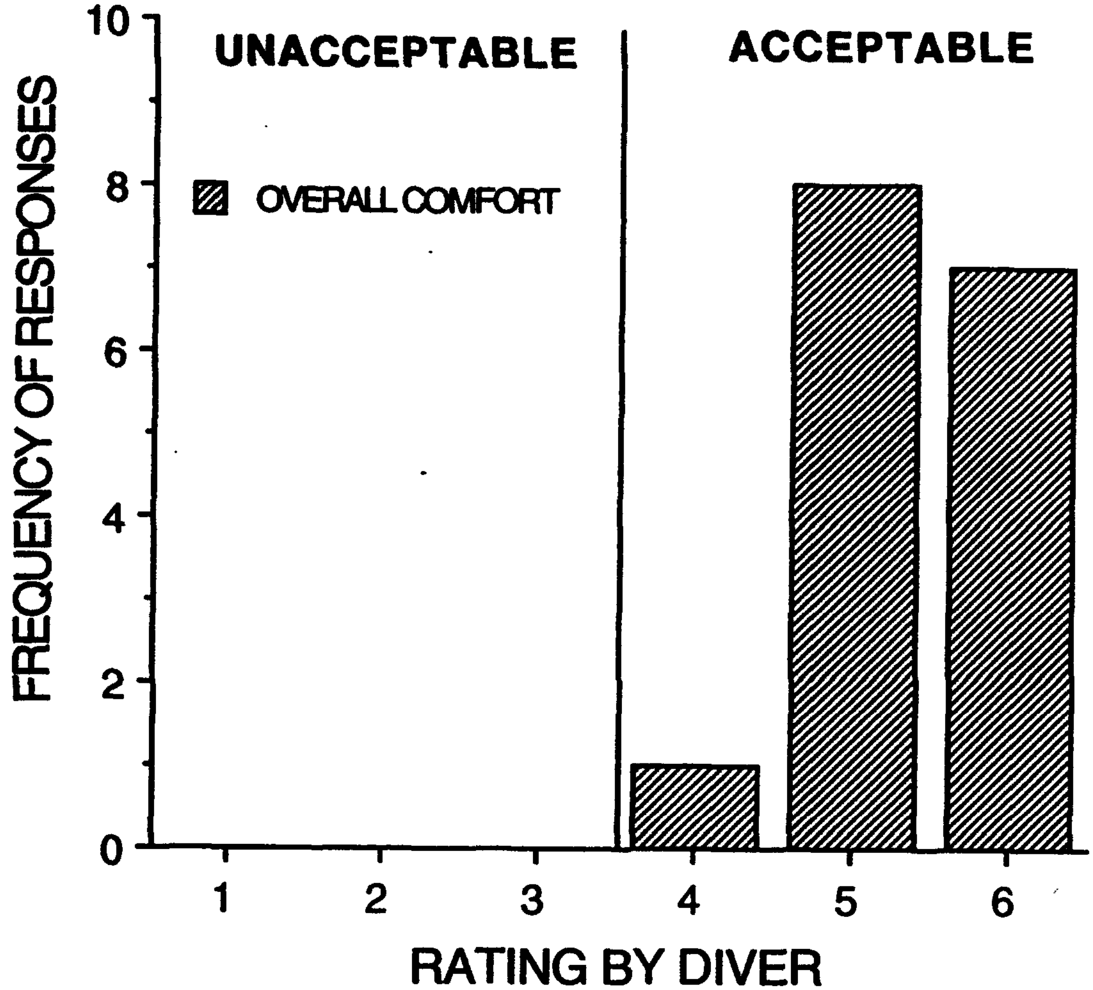

Figure 19. ARCTIC, Open Sea, Overall Comfort With Use

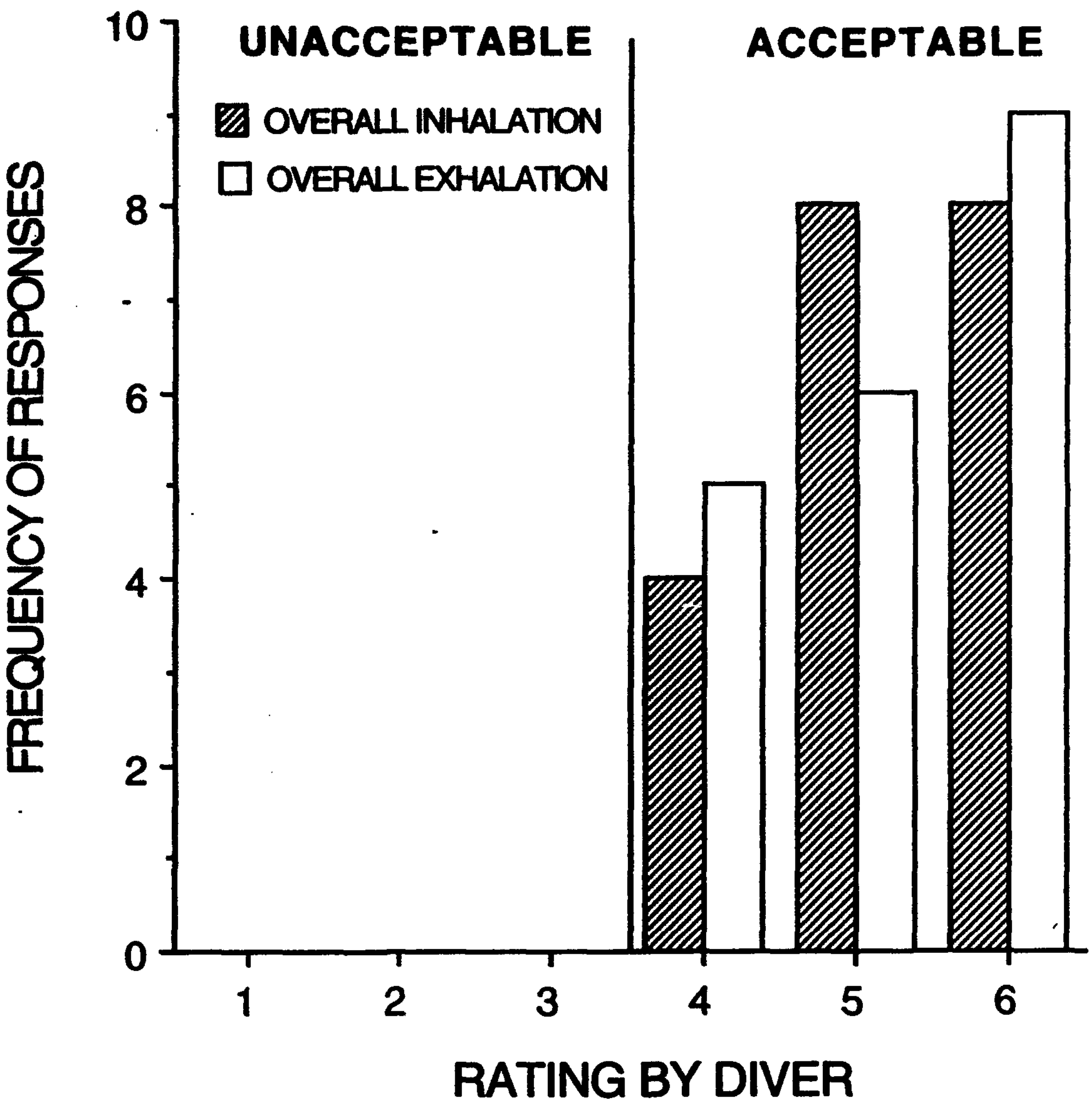

Figure 20. ARCTIC, OSF, Overall Inhalation/Exhalation

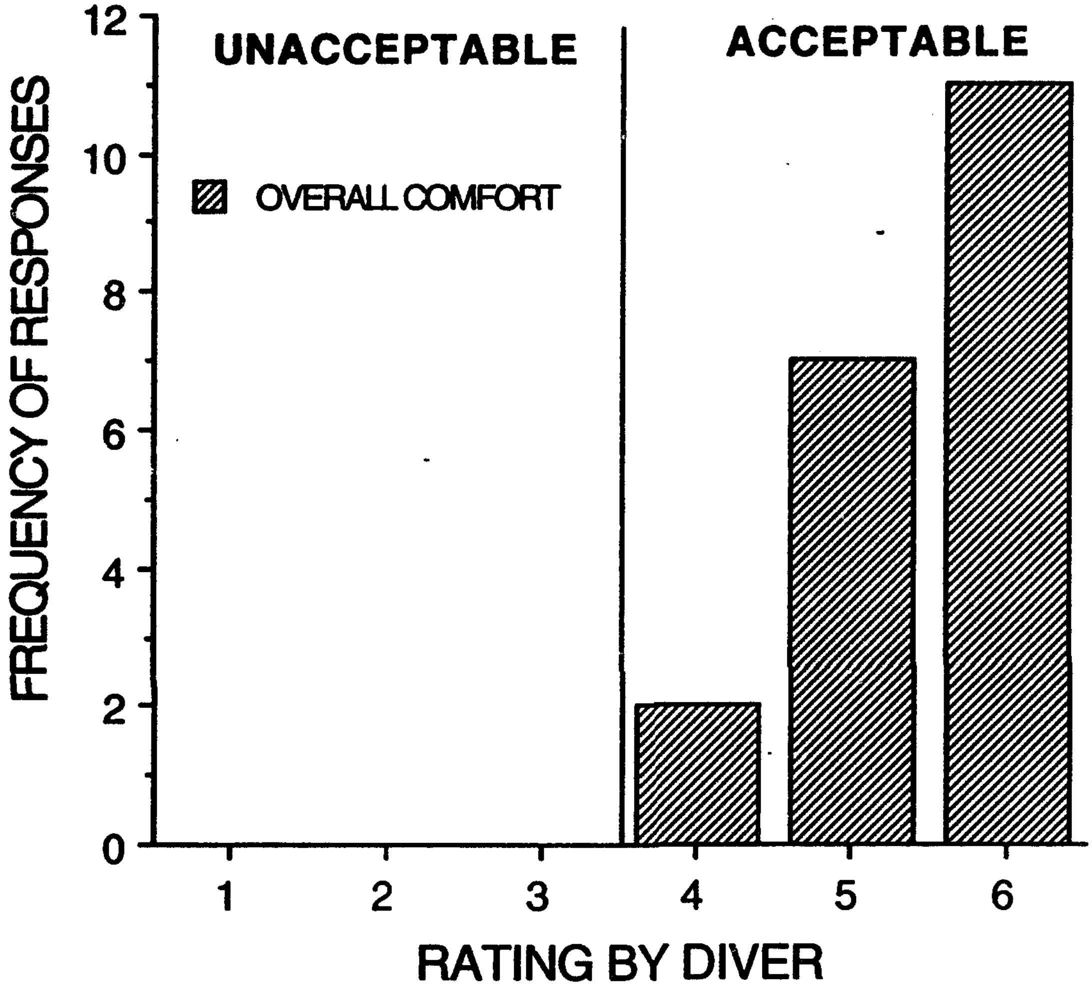

Figure 21. ARCTIC, OSF, Overall Comfort With Use

APPENDIX A

HUMAN FACTORS EVALUATION QUESTIONNAIRE SCUBA REGULATOR

Name of diver ______________________________

Date: __________ Regulator tag # ____

Number of years experience diving SCUBA? ________

Dive profile: (circle one) OSF / GULF Depth (fsw) _____ Duration (min)___ Water Temp (°F) ____

Brief description of dive ______________________________

Describe dress used for dive ______________________________

Were gloves worn during dive (yes/no)? ____ Type ______________________________

Testing associate: **Mfg/model of regulator** ______________________________

Overbottom pressure (kPa): Pre-test _____ Post-test ____

RATING SYSTEM:

1=extremely poor	3=not quite adequate	5=good
2=poor	4=adequate	6=excellent

RATE THE FOLLOWING WORK OF BREATHING PARAMETERS:

	inhalation	exhalation
a. Standing upright		
b. At a 45° face-up position		
c. At a 45° face-down position		
d. In a head-down position		
e. Prone position		
f. Supine position		
g. Overall rating		

OVERALL COMFORT OF REGULATOR:

4. How would you rate the comfort of the regulator bit in your mouth? . . . . ___
5. How would you rate the comfort of the regulator in terms of its relative buoyancy? . . ___
6. How would you rate the comfort of the regulator in terms of its range of motion? . . . ___
7. How would you rate the dispersion of air bubbles by the whisker? . . . . ___

USE AND OPERATION OF MASK:

8. How would you **rate** the ease of breathing the mask while at rest? .... ___

9. How would you **rate** the ease of breathing the mask at moderate work levels? ...... ___

10. How would you **rate** the ease of breathing the mask at heavy work levels? .... ___

11. How would you **rate** the size and location of the purge button? .... ___

12. How would you **rate** the operation of the purge button *with bare hands*? .... ___

13. How would you **rate** the operation of the purge button *with gloved hands*? .... ___

14. How would you **rate** the accessibility and operation of the dial-a-breath? .... ___

15. How would you **rate** the reduction in breathing resistance provided by the dial-a-breath? ___

16. How would you **rate** your comfort level diving this regulator? .... ___

17. Did you encounter a sustained, forceful free-flow with this regulator (yes/no)? ..... ___

18. If yes, describe the circumstances triggering the free-flow: ____________________________

____

____

19. Briefly describe what you consider the *best* feature of this regulator: ____________________

____

20. Briefly describe what you consider the *worst* feature of this regulator: ____________________

____

Please provide any additional comments about the regulator that you think are important, including suggestions you feel would enhance its performance/safety: ____________________________

____

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